AFOSR 4687 Final Report 49(638)-958 63-4-2

THE UNIVERSITY OF CHICAGO
CHICAGO 37 • ILLINOIS

THE ENRICO FERMI INSTITUTE
FOR NUCLEAR STUDIES

Office of the Director

October 15, 1962

Director, Physical Sciences
Air Force Office of Scientific Research
Attention: SRYN
Washington 25, D. C.

Dear Sir:

We submit herewith a preliminary report of the experimental work carried out under contract AF 49(638)-958 under the title "Quasi-free Proton-proton Scattering at 450 Mev." The experiment was quite successful and all our equipment worked as well or better than called for in the design. The resolution achieved by the spectrometer system was 3 Mev and the successful application of the peripheral dee reduced the problem due to accidental coincidence to negligible proportions.

The results revealed the details of nuclear structure in an unusually clear way and establishes this technique as one with the greatest significance for the study of nuclear structure. The results have just been reported to the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms held September 3-8, 1962 at the University of Padova, where they excited a considerable amount of interest. The full significance of the experiments will emerge only after rather extensive calculations have been completed. Some of these are already in progress. The experiments will serve as a crucial test of the various possible theories of nuclear structure.

It was quite clear that the experiments should be extended and that the apparatus which has functioned so satisfactorily, should be exploited to the fullest extent. This purpose will be served by the Air Force grant which is being processed.

We intend to supplement the present report by a more complete one which will contain more details of the experiment and its interpretation.

We thank the Air Force Office of Scientific Research for its support under this contract which, we feel, has made possible a significant advance in the understanding of nuclear structure.

Sincerely,

Herbert L. Anderson

HLA:mw

QUASI-FREE PROTON-PROTON SCATTERING IN LIGHT NUCLEI AT 450 Mev

H. Tyren, S. Kullander and R. Ramachandran

The Enrico Fermi Institute for Nuclear Studies
The University of Chicago
Chicago, Illinois

Abstract

Quasi-free proton-proton scattering in light nuclei has been studied experimentally at 450 Mev incident proton energy. Energy and angular correlations of the two emerging protons have been measured using two double focusing magnetic spectrometers and a multi-channel electronic detector system.

QUASI-FREE PROTON-PROTON SCATTERING IN LIGHT NUCLEI AT 450 Mev*

H. Tyren, S. Kullander and R. Ramachandran

The Enrico Fermi Institute for Nuclear Studies
The University of Chicago

It was demonstrated in the initial experiments at Uppsala[1] that it is possible to study quasi-free p-p scattering in individual shells in light nuclei. It was pointed out in the original articles[1] and later verified[2] that angular correlation experiments should give information on the momentum distribution of the separated proton groups. Continued experiments at Uppsala and other laboratories[3] have proved the validity of this statement. The distortions of the incoming and outgoing waves due to absorption and refraction in the nucleus reduce considerably the observable cross sections. These distortions should be smaller at higher energies.[4]

In order to give more information on the tightly bound protons in nuclei and in particular to give a closer picture of the true momentum distributions, quasi-free p-p scattering experiments have been carried out at 450 Mev using the

---

* Research supported by the U. S. Air Force Office of Scientific Research, Contract No. AF 49(638)958.

synchrocyclotron at the Enrico Fermi Institute for Nuclear Studies, University of Chicago. The results of preliminary experiments using range technique[5] encouraged us to build a much more elaborate instrumentation using two large identical double focusing magnetic spectrometers and a multi-channel electronic detector system for the momentum analysis of the two emerging protons. This equipment has very recently been used to study momentum distributions of protons in several light nuclei.

During part of the experiment a good beam duty cycle was obtained with a peripheral D in the cyclotron. The magnets are of the zero gradient fringe focusing type and weigh approximately 30 tons each. The radius of curvature is 135 cm and the deflecting angle 135°. The spectrometers are symmetrically designed and the protons enter and leave the magnets at 51° to the normal of the effective magnetic boundary which is very close to a straight line to give correct first order focusing. The solid angle is defined by a slit at the magnet entrance and is 3×10^{-3} ster. in the experiment reported. The corresponding plane angle in the horizontal scattering plane is 3.6°. The interior magnetic field is homogeneous to about one part in 3000. The spectrometers are pivoted around the scattering center by a remotely controlled machinery.

The protons are detected by four momentum channels each consisting of two scintillators in coincidence. The defining crystal has an energy width, in the magnetic field range

considered, of approximately 2 Mev. The other crystal is common for the four momentum channels. The coincidence outputs are combined in an array of 4 x 4 final coincidence and register units. Accidentals are simultaneously measured in identical units. The total energy resolution is approximately 3 Mev for the 2 Mev channels and the size of the triangular shaped target used. The two scattering angles are equal in the experiment and denoted by $\theta_L = \theta_R$.

Energy spectra have been measured for the elements and angles shown in Table 1. The separation energies are given for pronounced peaks in the spectra. The 11 Mev separation energy in B^{11} is obtained by resolving the energy spectrum. The 1s peaks in B^{11} and O^{16} has not been measured and no clear evidence for the 1p and 1s peaks in Ca^{40} has been found, but this part of the Ca spectrum has not been carefully studied. The Li^6 spectrum at 39° is shown as an illustration.

Angular correlation measurements have generally been carried out by measuring peak values with good statistics. The free hydrogen peak interference in the Li^6 spectra will lower the points in the valley only slightly. The angular scale given is by a later check found to be in error and $\theta_L = \theta_R$ should be reduced by approximately 0.5°. Angular correlations are measured for the elements and proton groups of Table 2 and the results are shown in the picture.

Absolute cross-sections have been determined but are not yet calculated.

A computer program using distorted wave calculations for analyzing the results will be carried out in collaboration with T. Berggren, Uppsala University.

Table 1

		Li^6	Li^7	Be^9	B^{10}	B^{11}	C^{12}	O^{16}	Ca^{40}
$\Theta_L = \Theta_R$		39.0°	39.0°	38.2°	46.5°	46.7°	40.0°	46.4°	41.6°
	several angles			41.0°	41.5°			50.0°	45.0°
	for H-interf.			42.0°					47.5°
				45.0°					50.1°
									52.0°
Separ. Energ. Mev	$1s^{1/2}$	22.3	23.4	26.4	32.4		36		
	$1p^{3/2}$	5.2	10.0	17.5	6.7 16.5	11 15.1 21.1	16	Diff. 7.1	
	$1p^{1/2}$								
	$1d^{5/2}$								8.3
	$2s^{1/2}$								10.6
	$1d^{3/2}$								14.5

Table 2

Li^6	Li^7	Be^9	C^{12}	O^{16}
$s^{1/2}$	$s^{1/2}$	$s^{1/2}$		
$p^{3/2}$	$p^{3/2}$	$p^{3/2}$	$p^{3/2}$	$p^{3/2}$
				$p^{1/2}$

REFERENCES

1) H. Tyren, Th. A. J. Maris and P. Hillman, Nuovo Cimento 6, 1507 (1957)

Th. A. J. Maris, P. Hillman and H. Tyren, Nucl. Phys. 7, 1 (1958)

H. Tyren, P. Hillman and Th. A. J. Maris, Nucl. Phys. 7, 10 (1958)

2) P. Hillman, H. Tyren and Th. A. J. Maris, Phys. Rev. Letters 5, 107 (1958)

3) H. Tyren and P. Isacsson, Second Annual Moscow Conference on Nuclear Reactions 1960 and Proc. of the International Conference on Nuclear Structure, Kingston, 429 (1960)

T. J. Gooding and H. G. Pugh, Nucl. Phys. 18, 46 (1960).

B. Gottschalk and K. Strauch, Phys. Rev. 120, 1005 (1960)

J. P. Garron, J. C. Jacmart, M. Riou and C. Ruhla, J. Phys. 22, 622 (1961) and Rutherford Jubilee Int. Conf. Manchester (1961)

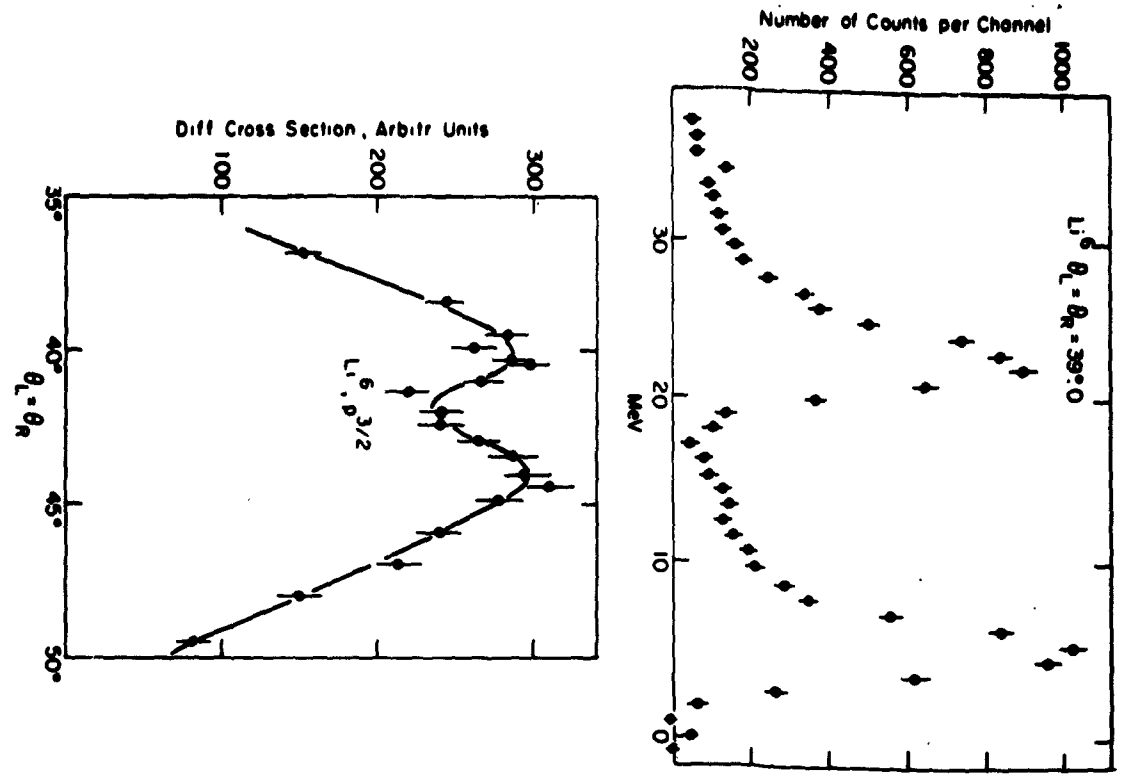
J. P. Garron, J. C. Jacmart, M. Riou, C. Ruhla, J. Teillac, C. Caverzasio and K. Strauch, Phys. Rev. Letters 7, 261 (1961)

4) See Ref. 1)b

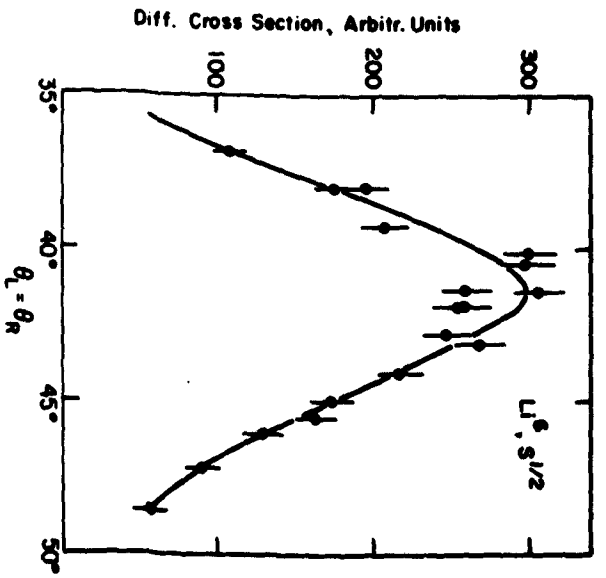
Th. A. J. Maris, Nucl. Phys. 9, 577 (1958)

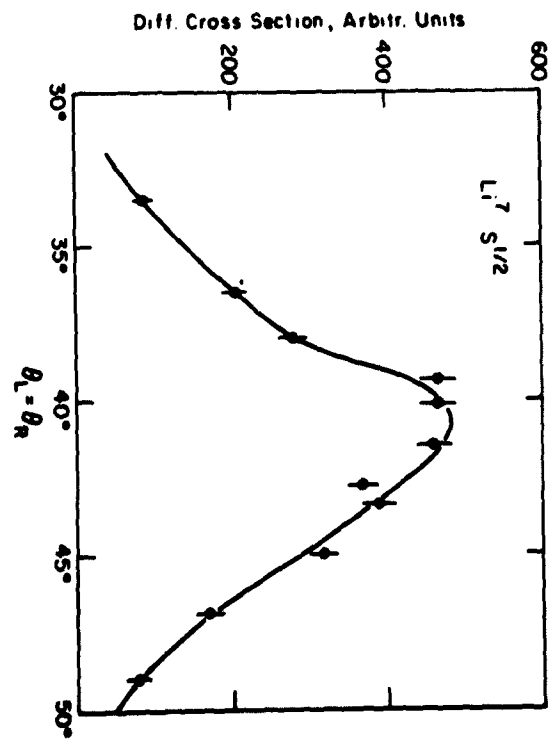
G. Jacob and Th. A. J. Maris, Nucl. Phys. 20, 440 (1960)

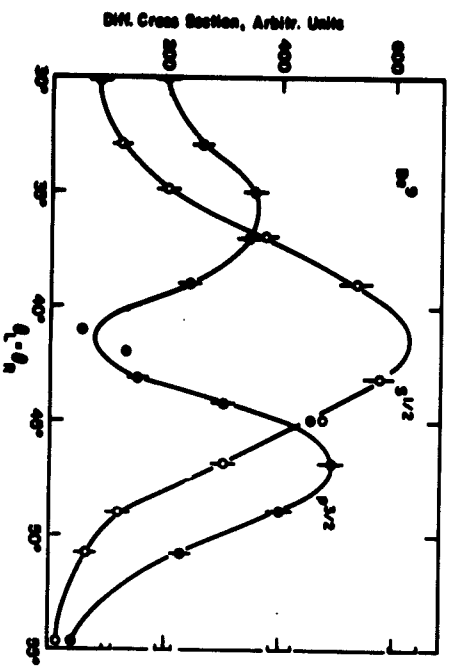
5) H. Tyren and P. Isacsson, Ref. 3.

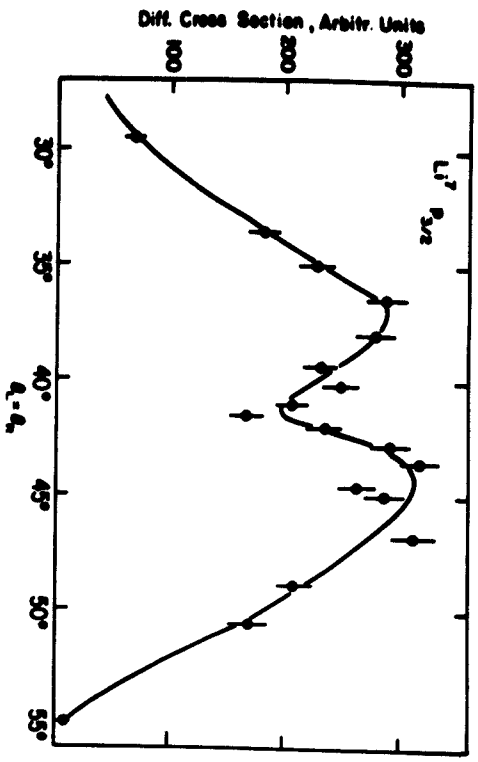

Number of Counts per Channel
200
400
600
800
1000
30
20
10
0
MeV
Li^6 $\theta_L = \theta_R = 39°.0$

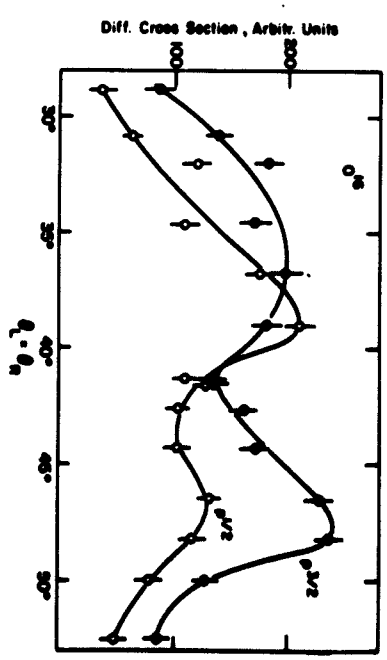
Diff Cross Section, Arbitr Units
100
200
300
35°
40°
45°
50°
$\theta_L = \theta_R$
Li^6, $p_{3/2}$

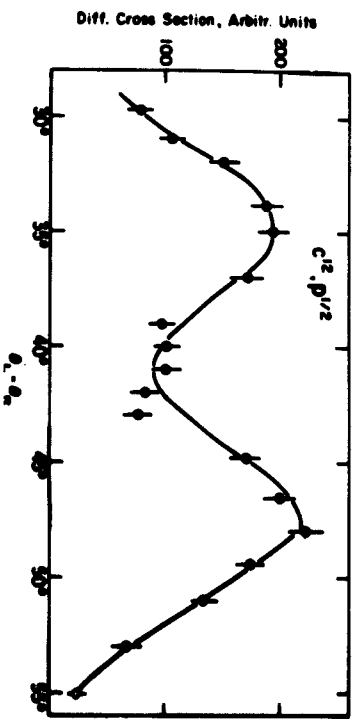

Diff. Cross Section, Arbitr. Units
100
200
300
35°
40°
45°
50°
$\theta_L = \theta_R$
Li^6, $s_{1/2}$


Diff. Cross Section, Arbitr. Units
200
400
600
30°
35°
40°
45°
50°
$\theta_L = \theta_R$
Li^7 $s_{1/2}$


Diff. Cross Section, Arbitr. Units
Be⁹
s1/2
p3/2


Diff. Cross Section, Arbitr. Units
Li⁷
p3/2


Diff. Cross Section, Arbitr. Units
O¹⁶
p3/2
p1/2


Diff. Cross Section, Arbitr. Units
C¹², p1/2